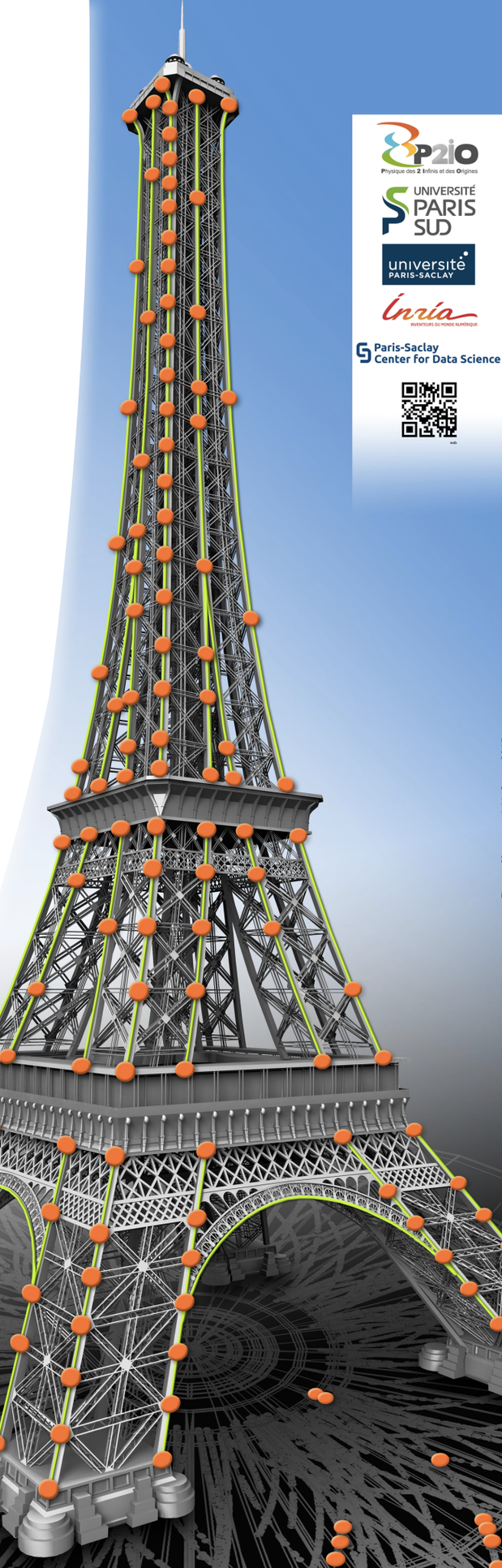
Status of the ACTS Project

A Common Tracking Software



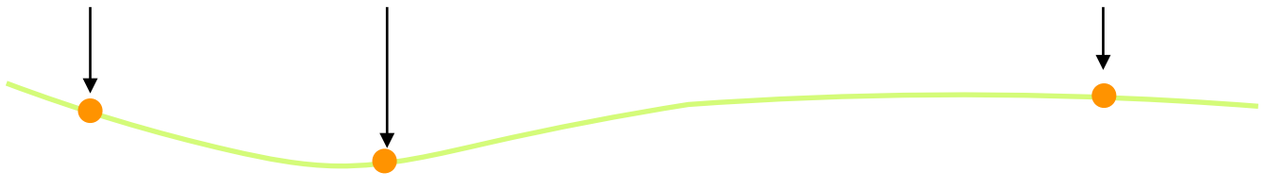
A. Salzburger (CERN) on behalf of the ACTS team

Motivation and Mission statement

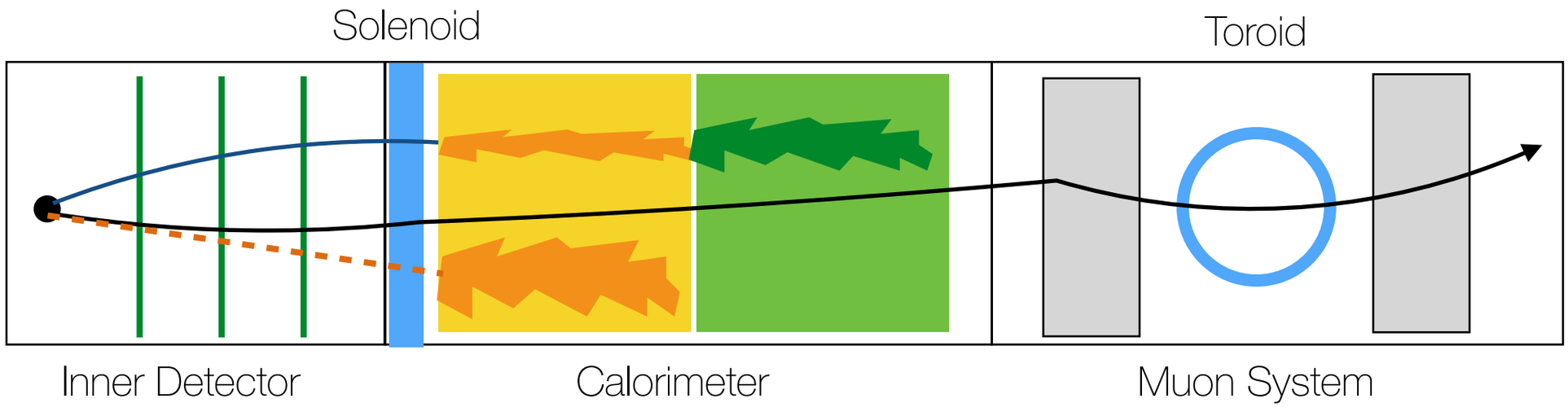
- LHC Run-1/2 exceeded all expectations in terms of provided data
  - design pile-up of <μ> ~23 exceed (for Run-2 de facto with a factor 2)
  - trackers and track reconstruction worked extremely well

- LHC track reconstruction software applications
  - extremely well tested code (10^{10} events with up to 10^3 tracks/event)
  - extremely high performant code

- However, …
  - code base and concepts are <fill in your favourite word for ageing>
  - HL-LHC and future FCC will bring even more demanding
  - developments in tracker, computing hardware and algorithmic concepts



History | CDOT2016



Tracking

Geometry (TrkDetDescr)	Event Data Model (TrkEvent)	A Extrapolation (TrkExtrapolation)	A Fitting (TrkFitter)	A Calibration, general (TrkTools)	A Alignment (TrkAlignment)

InnerDetector

EDM (InDetRecEvent)	A Geometry (InDet TrackingGeometry)	A Tools (InDetRecTools)

Calorimeter

EDM	A Geometry (Calo TrackingGeometry)

MuonSpectrometer

EDM (MuonRecEvent)	A Geometry (Muon TrackingGeometry)	A Tools (MuonRecTools)

A … embedded in Gaudi/Athena structure with AlgTools/Algorithms/Services

History | CDOT2016

Tracking					
Geometry (TrkDetDescr)	Event Data Model (TrkEvent)	G/A Extrapolation (TrkExtrapolation)	G/A Fitting (TrkFitter)	G/A Calibration, general (TrkTools)	G/A Alignment (TrkAlignment)

a-tracking-sw

Attempt to encapsulate the ATLAS Tracking software from ATLAS

currently restricted access

★ 0 | 1 | SSH | HTTPS | ssh://git@gitlab.cern.ch:7999/ | GLOBAL

65 COMMITS | 5 BRANCHES | 0 TAGS | 13.21 MB | ADD CHANGELOG | ADD LICENSE | ADD CONTRIBUTION GUIDE

A Tracking Software (ATS) Project

This library is based on the track reconstruction software developed by the ATLAS Collaboration.

The main philosophy is to provide high-level track reconstruction modules that can be specified for detector technologies by simple extension.

- Event Data Model (EDM)
- Geometry
- track reconstruction tools

The library is attempted to build against Gaudi and Gaudi-Athena, while additional external dependencies are kept at a minimum.

double build philosophy

ATS to ACTS

- Established an open-source ACTS project at CERN/gitlab
  - growing functionality
  - growing developers base
    mainly from ATLAS and FCCSW
  - main clients are
    FCCSW (mainly for FCC-hh)
    Tracking ML challenge (starting)
    ATLAS
  - Latest release 0.03.01,
    in synch with FCC development

Releases

- latest development version
  Open issues | git repository | Documentation
- Version 0.03.01
  Release Notes | Download | Documentation
  28 Nov 2016 14:26 CET.
- Version 0.03.00
  Release Notes | Download | Documentation
  11 Nov 2016 17:25 CET.
- Version 0.02.01
  Release Notes | Download | Documentation
  26 Sep 2016 20:37 CEST.
- Version 0.02.00
  Release Notes | Download | Documentation
  18 Sep 2016 01:04 CEST.
- Version 0.01.01
  Release Notes | Download | Documentation
  13 Jun 2016 12:31 CEST.
- Version 0.01.00
  Release Notes | Download | Documentation
  13 Jun 2016 10:36 CEST.

http://acts.web.cern.ch/ACTS/

https://gitlab.cern.ch/acts/a-common-tracking-sw

https://its.cern.ch/jira/projects/ACTS/summary

Dependencies, Repository and Modules

a-common-tracking-sw

Core
- Event Data Model
- Geometry & building
- Transport
- Fitting
- Pattern recognition

Plugins
- DD4HepPlugin
- TGeoPlugin

Build infrastructure
- gcc (>= 6.2) or clang (>= 3.8)
- cmake (>= 3.5)

Core Dependencies
- eigen (linear algebra)
- boost (unit testing)

Plugin Dependencies (optional)
- DD4hep
- ROOT (> 6.0)

acts-mini-fw

Core
Plugins

- Geant4 for material mapping
- ROOT for writing

acts-fatras (not yet public)

Core
Plugins

- Geant4 for hadronic interactions

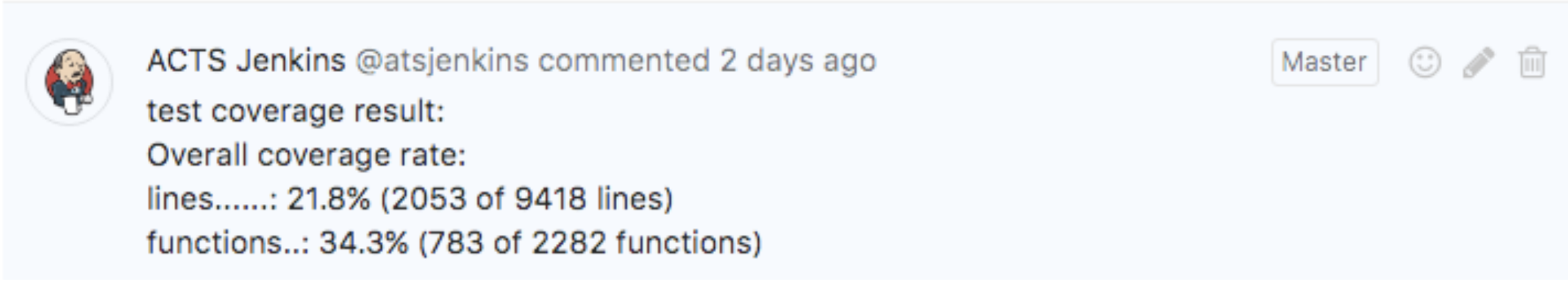
docker images available

Testing, testing, testing

- Aim is to provide long-term maintainable code/toolbox
  - testing is crucial

- Continuous integration testing using Jenkins for every merge request
  - CI success is one required approver for accepting a merge request
  - **Human review** is the second required approval
  - aim for minimal disruption of integration

- Unit test suite is growing, but certainly not yet optimal …
  - based on boost test framework



Documentation & code style

- Aim is to provide long-term maintainable code/toolbox
  - documentation is crucial, consistent code-style is essential

- doxygen for code documentation
  - one central documentation source
  - contribution guide gives guidelines for doxygen usage
  - code is formatted to clang-format by CI system

Detailed Description

Class for material mapping.

This class should be used to map material from the full and detailed detector geometry onto the simplified ACTS geometry. It offers options to map, average and finalize the material. One **MaterialTrackRecord** (containing all the MaterialSteps along a Track) is mapped by using the function **Acts::MaterialMapping::mapMaterial()**. The mapping process then extrapolates into the same direction starting from the same point as the **MaterialTrackRecord** through the ACTS geometry and finds the closest surface of a layer which is marked to carry support material. The material is assigned to the closest layer (forward or backward) to the bin at the assigned position on the layer. Along one track in one bin of a layer the material is averaged:

$$\frac{t}{x_0} = \sum_{i=1}^{n} \frac{t_i}{x_i} \qquad \rho = \frac{\sum_{i=1}^{n} t_i \rho_i}{\sum_{i=1}^{n} t_i}$$

$$\frac{t}{\Lambda_0} = \sum_{i=1}^{n} \frac{t_i}{\Lambda_i} \qquad A = \frac{\sum_{i=1}^{n} \rho_i A_i}{\sum_{i=1}^{n} \rho_i}$$

$$sensper = \frac{\sum_{i=1}^{n} sensV_i}{\sum_{i=1}^{n} V_i} \qquad Z = \frac{\sum_{i=1}^{n} \rho_i Z_i}{\sum_{i=1}^{n} \rho_i}$$

t...thickness, x_0...radiation length, Λ_0...interaction length, sensper...sensitive percentage, V...Volume, ρ...density, A...mass number, Z...atomic number

Doxygen http://acts.web.cern.ch/ACTS/latest/doc/index.html

Pillars of track reconstruction

- **Geometry**
  - ACTS provides a plugin algorithm for different geometry backends
  - helper tools in place to translate this into ACTS geometry
  - automated material transcript from full (Geant4) detector geometry

- **Event Data Model**
  - ACTS provides a standard implementation for track parameters
    parameterisation can be changed if needed
  - Measurement description does not restrict you
    1-N dimensional measurements

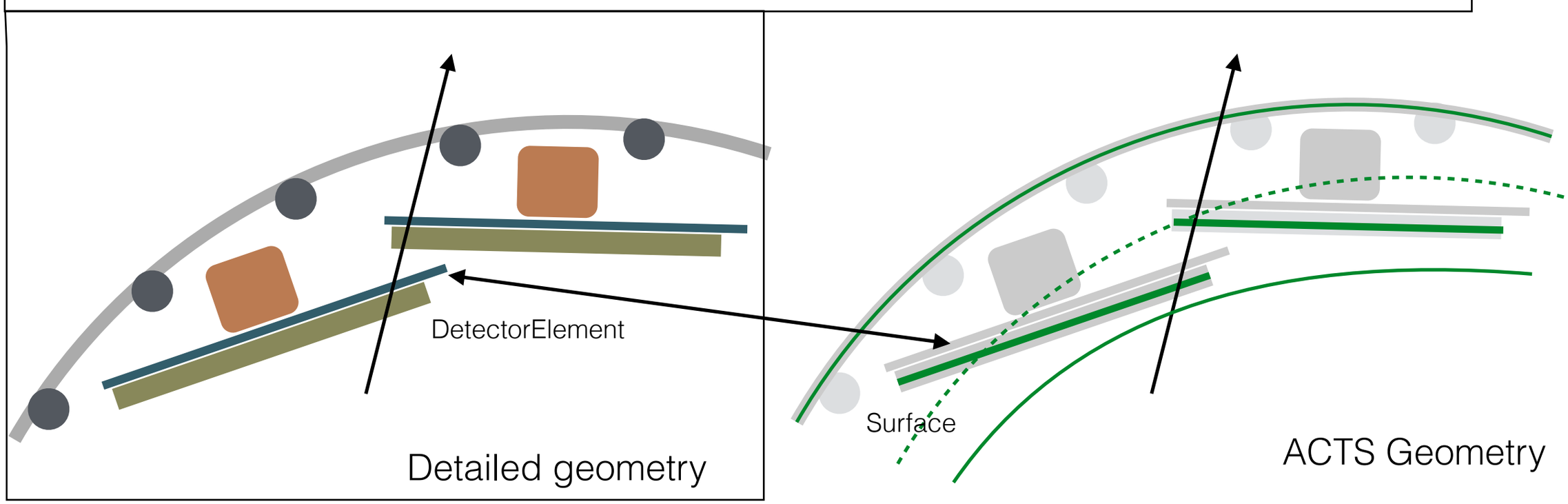
- **Algorithms**
  - ACTS provides Extrapolation/Propagation through arbitrary magnetic field
    optimised for ACTS detector geometry
  - Track fitters, pattern recognition algorithms, fast simulation are in preparation

Binding/Transcript of Geometry

- ACTS builds tracking geometry model from detailed geometry input

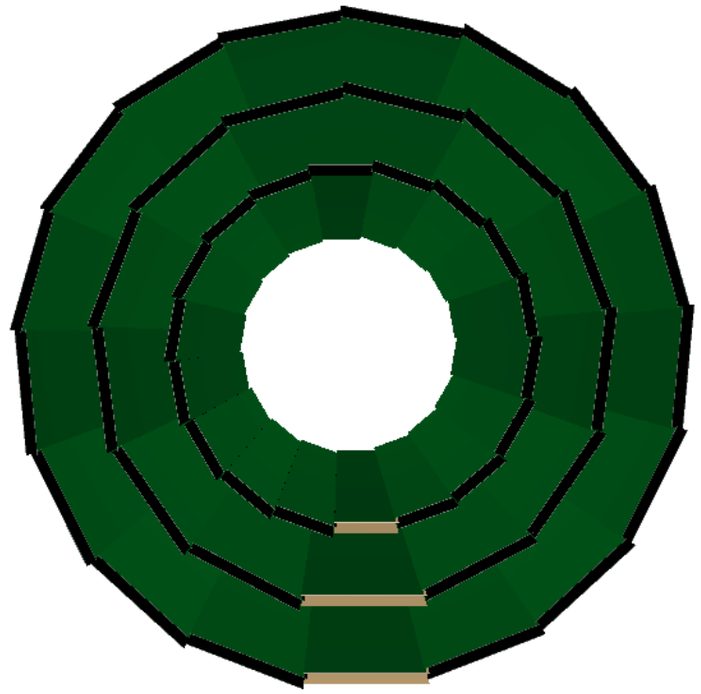
```
namespace Acts {
  /// doxygen documentation
  class DetectorElementBase {
    /// the according represented surface
    virtual const Surface& associatedSurface() const = 0;
  };
}
```

```
class MyDetectorElement {
   /// @copydoc DetectorElementBase::asscociatedSurface
   const PlaneSurface& associatedSurface() const;
};
```



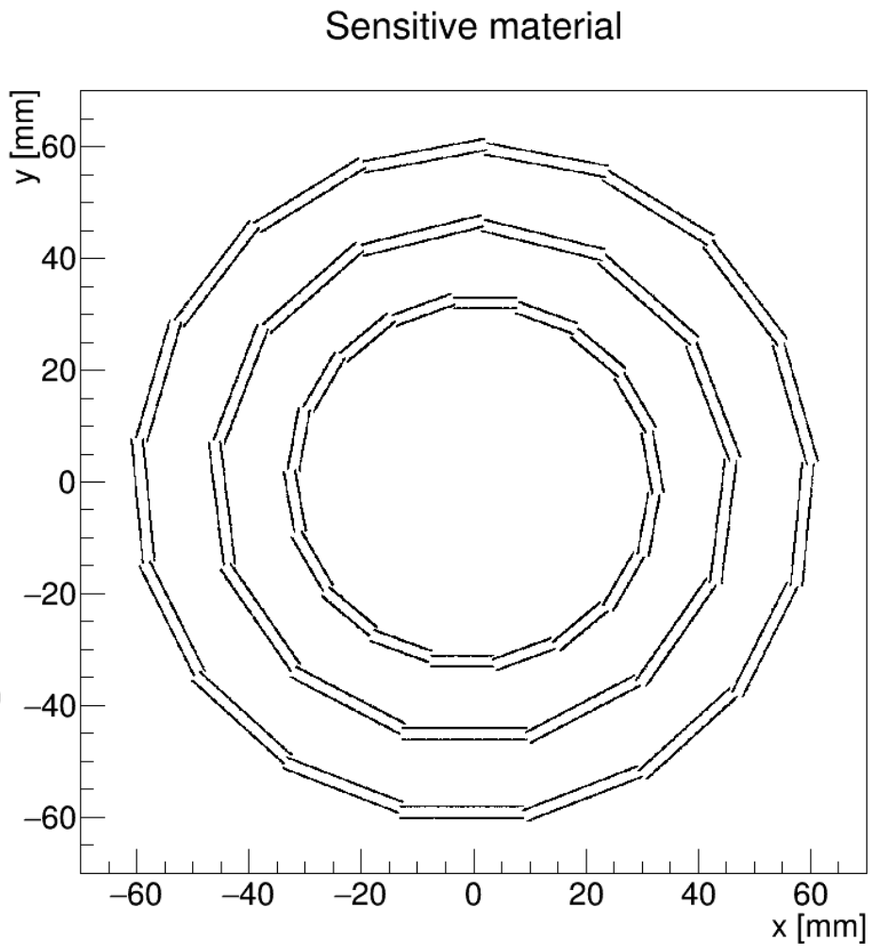
Geometry Examples - DD4Hep

- Different detectors have been built in ACTS with DD4Hep input
  - FCC-hh detector
  - CLIC detector example
  - ATLAS IBL description



- A dedicated DD4Hep/TGeo plugin provided within ACTS
  - DD4Hep uses TGeo in the background for as a modeller (also TkLayout support)
  - common TGeoPlugin used for DD4Hep geometry backend and TGeo backend

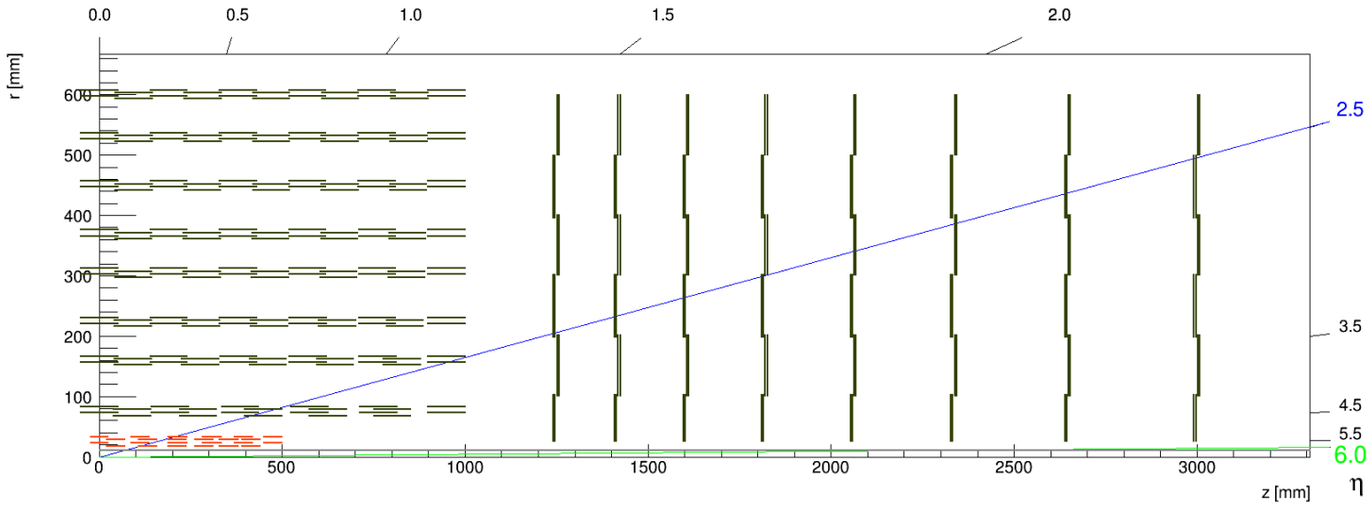
```
std::unique_ptr<Acts::TrackingGeometry>
convertDD4hepDetector(DD4hep::Geometry::DetElement worldDetElement,
                      Logging::Level loggingLevel   = Logging::Level::INFO,
                      BinningType    bTypePhi       = equidistant,
                      BinningType    bTypeR         = equidistant,
                      BinningType    bTypeZ         = equidistant,
                      double         layerEnvelopeR = 0.,
                      double         layerEnvelopeZ = 0.);
```



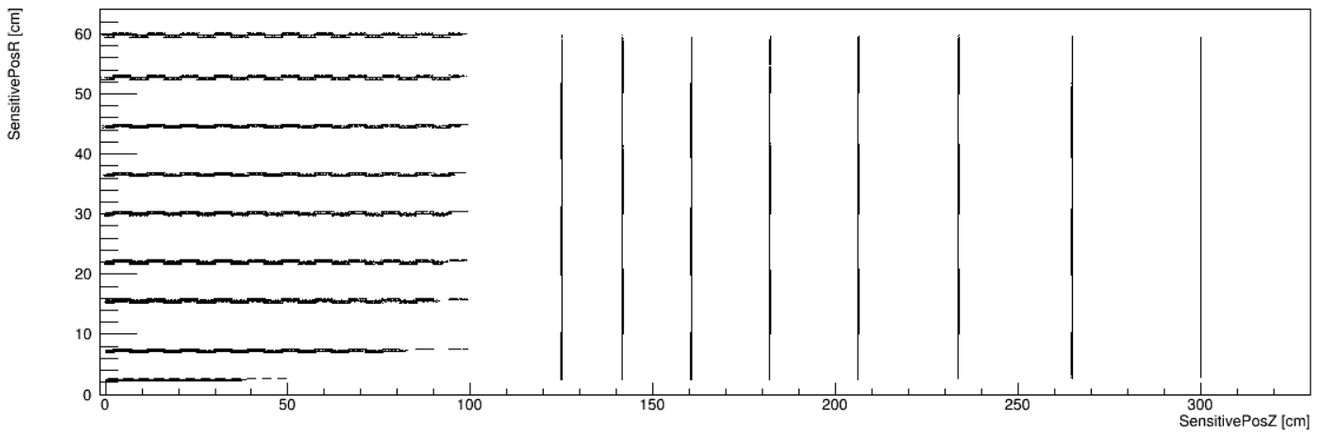
Geometry Examples - FCC studies

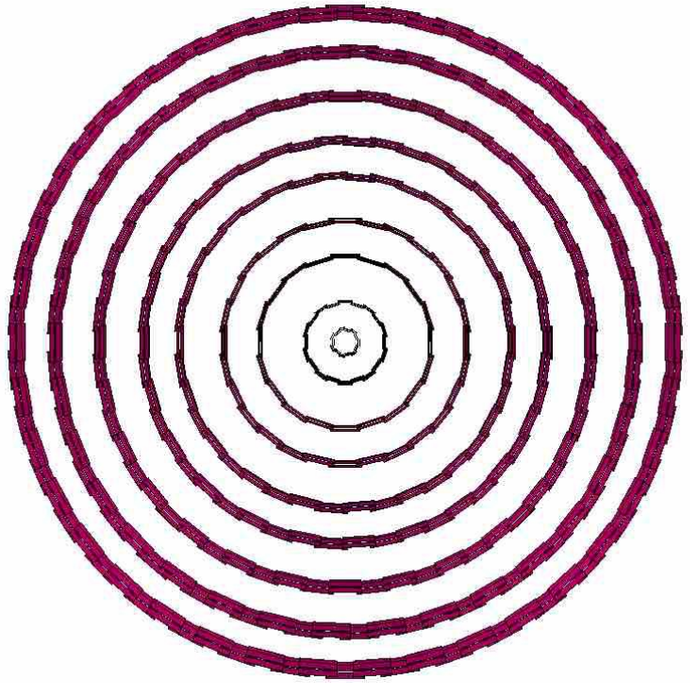
- FCC-hh tracker design workflow
  - starting with TkLayout tool (CMS)
  - translation into TGeo (DD4Hep) -> ACTS

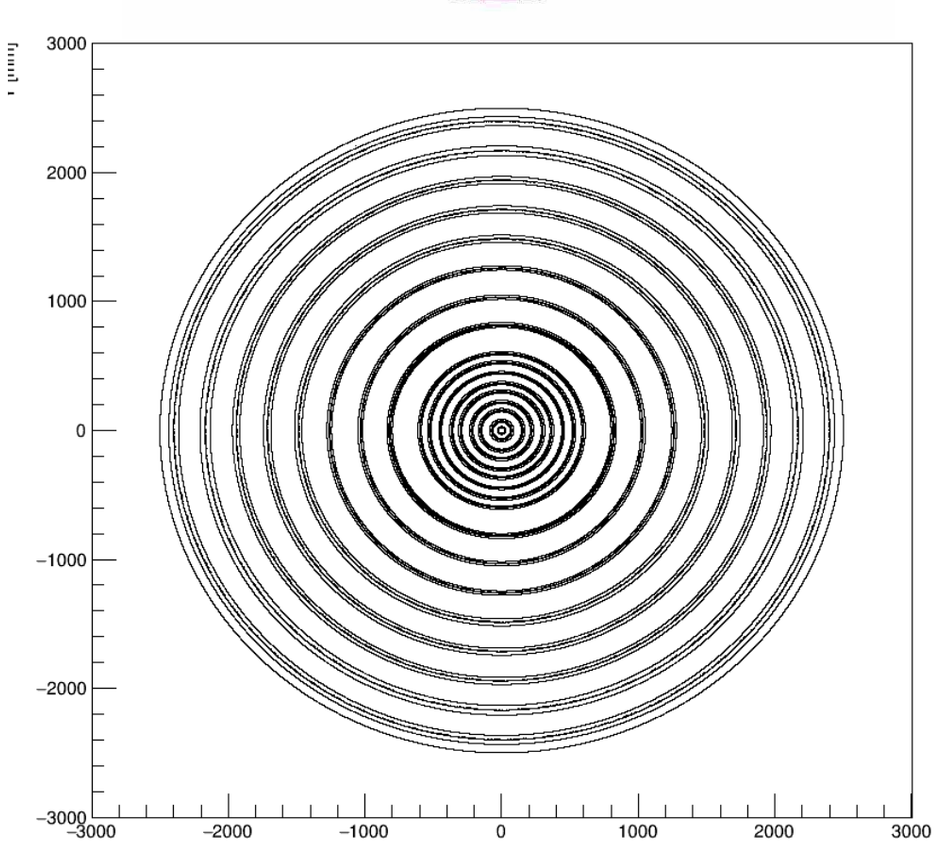
TkLayout design tool



translated into DD4hep and used in ACTS



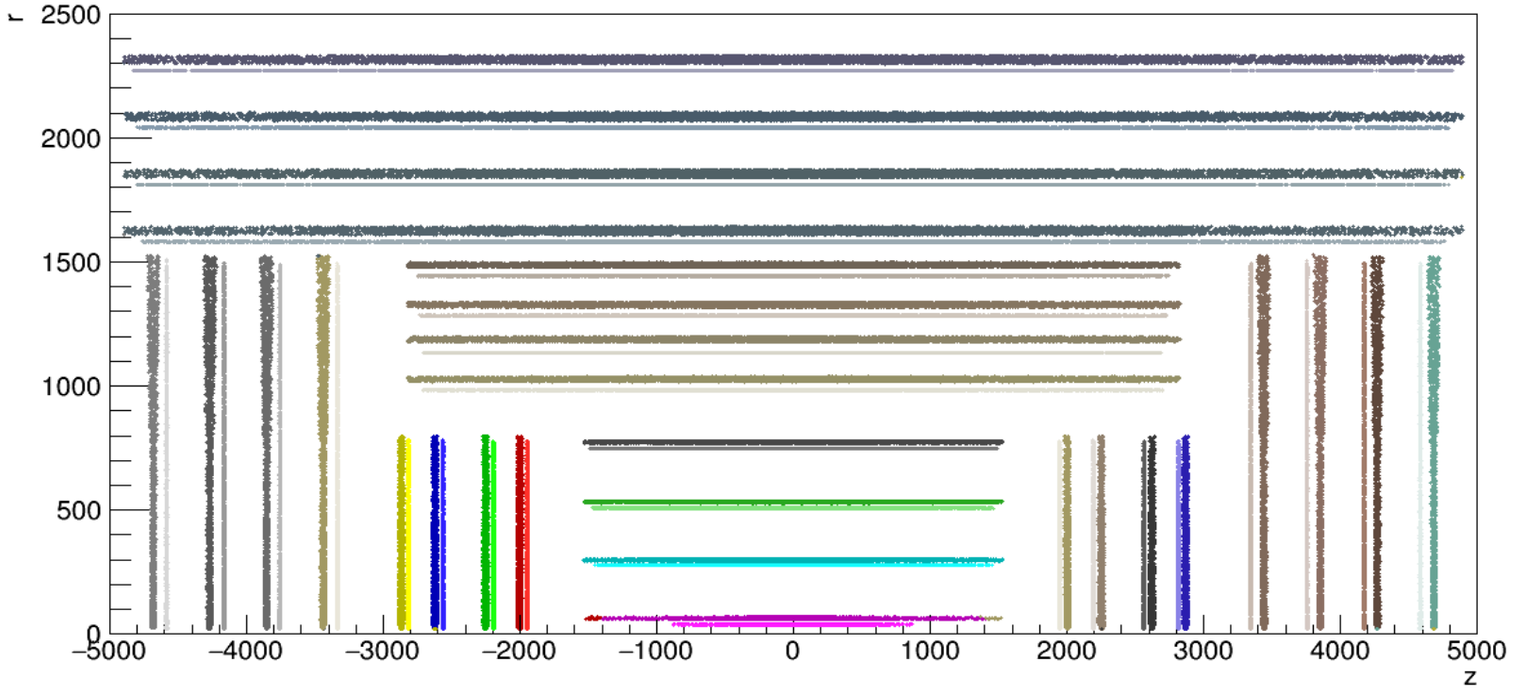


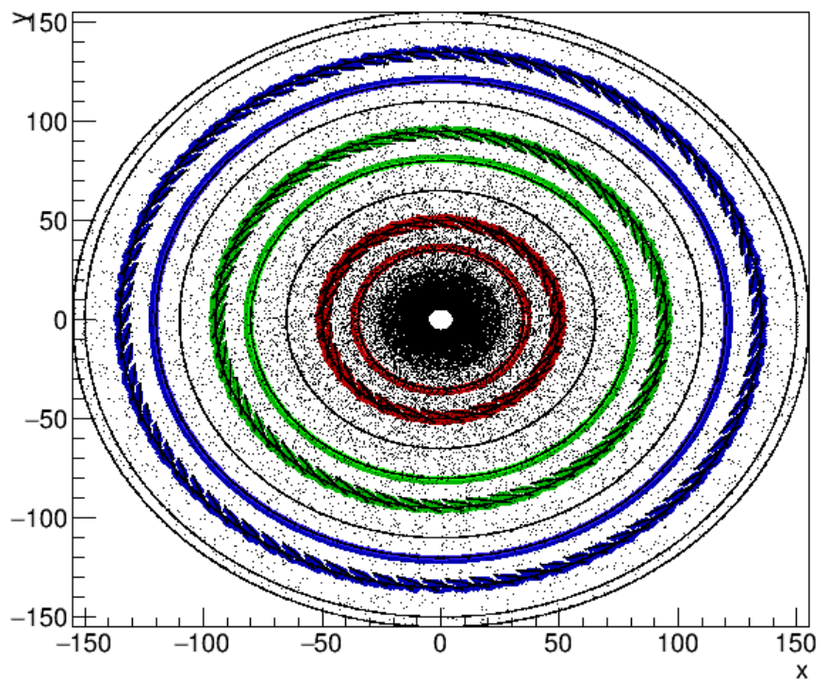


Material description & mapping

- Tracker needs an appropriate material description
  - usually simplified version of full simulation description
  - often used as material description for fast simulation

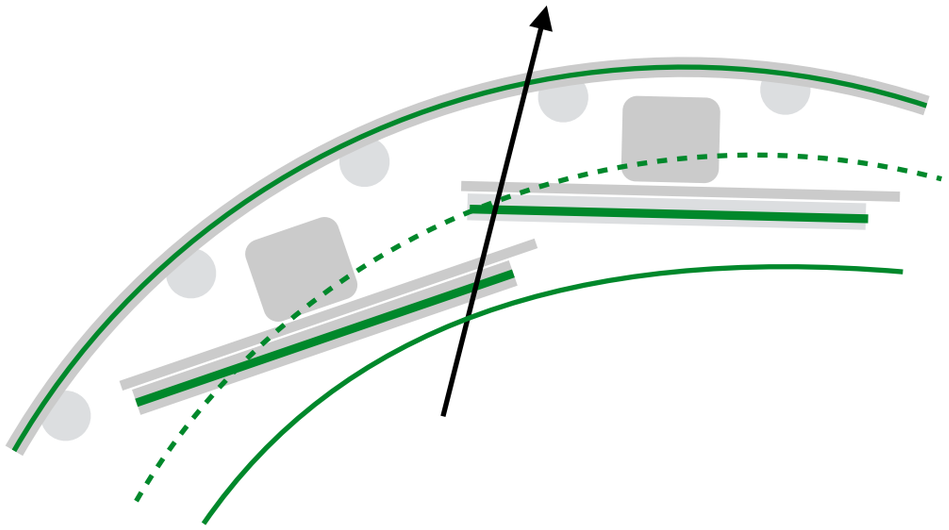
- Any geometry backend that also creates a full Geant4 description
  - automated material mapping procedure in place
  - uses Geant4 detector material and maps it onto chosen ACTS geometry structure

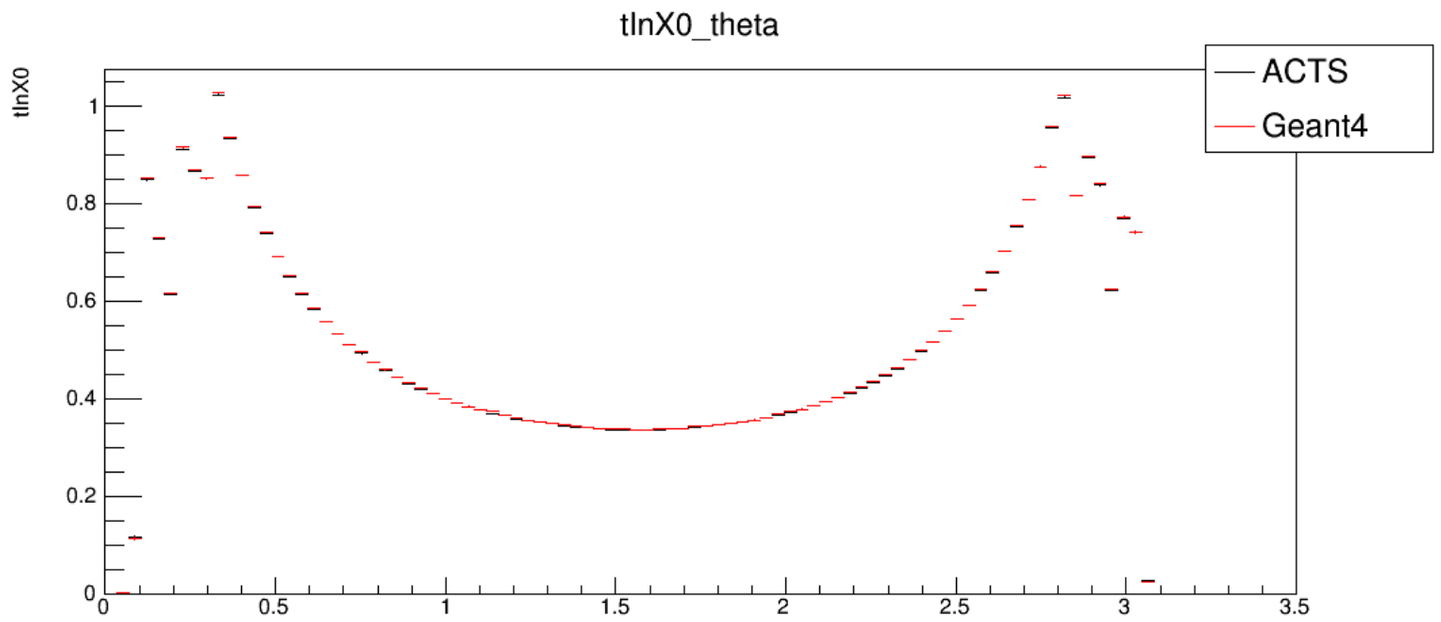


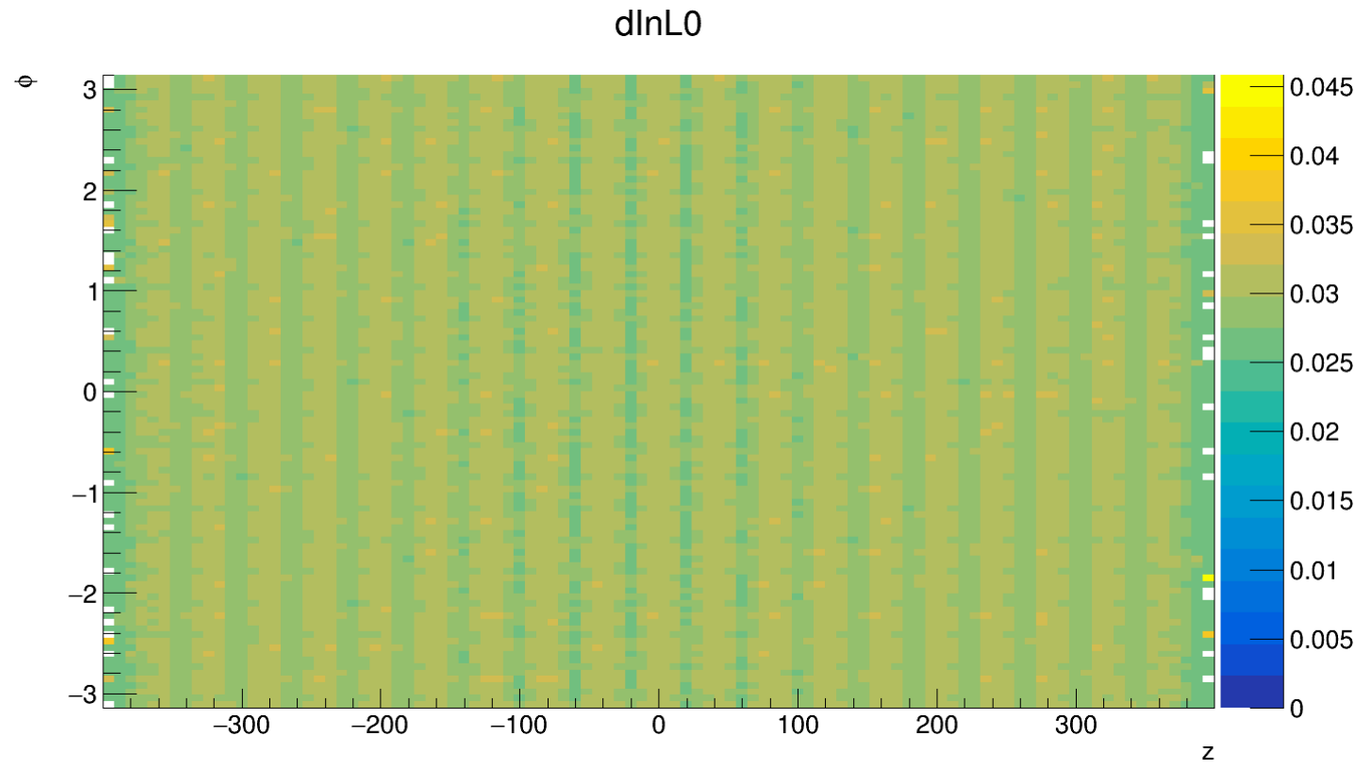


Material mapping - examples

- All ACTS surfaces can carry material
  - mapping targets to be chosen
  - 0,1,2 dimensional binning
- Alternatively material maps can be also provided externally
  - e.g. through direct transcript







Event Data Model - track parameterisation

- Fixed-size track parameterisation

  - size can by chosen at compile time as a template parameter `NGlobalPar` (e.g. extend with time, see talk of **L. Gray**)

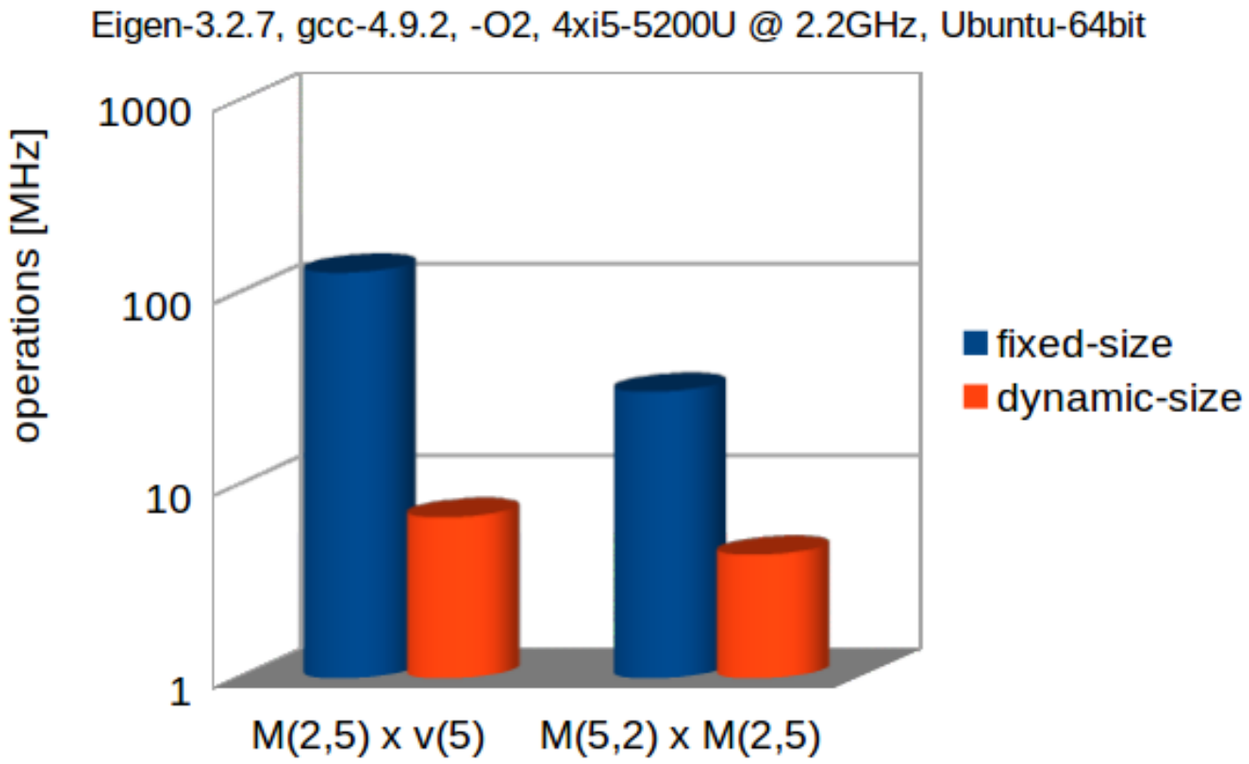
  - default parameterisation follows ATLAS choice

    all of the derivates needed are available & tested

  - parameterisation can be chosen differently, if wanted:

    Jacobian matrices to curvilinear need to be provided

    measurement mapping functions need to be provided



CDF $\mathbf{q}'' = (l_1, l_2, \phi, \cot(\theta), C)$

CMS $\mathbf{q}' = (l_1, l_2, \phi, \lambda, q/p)$

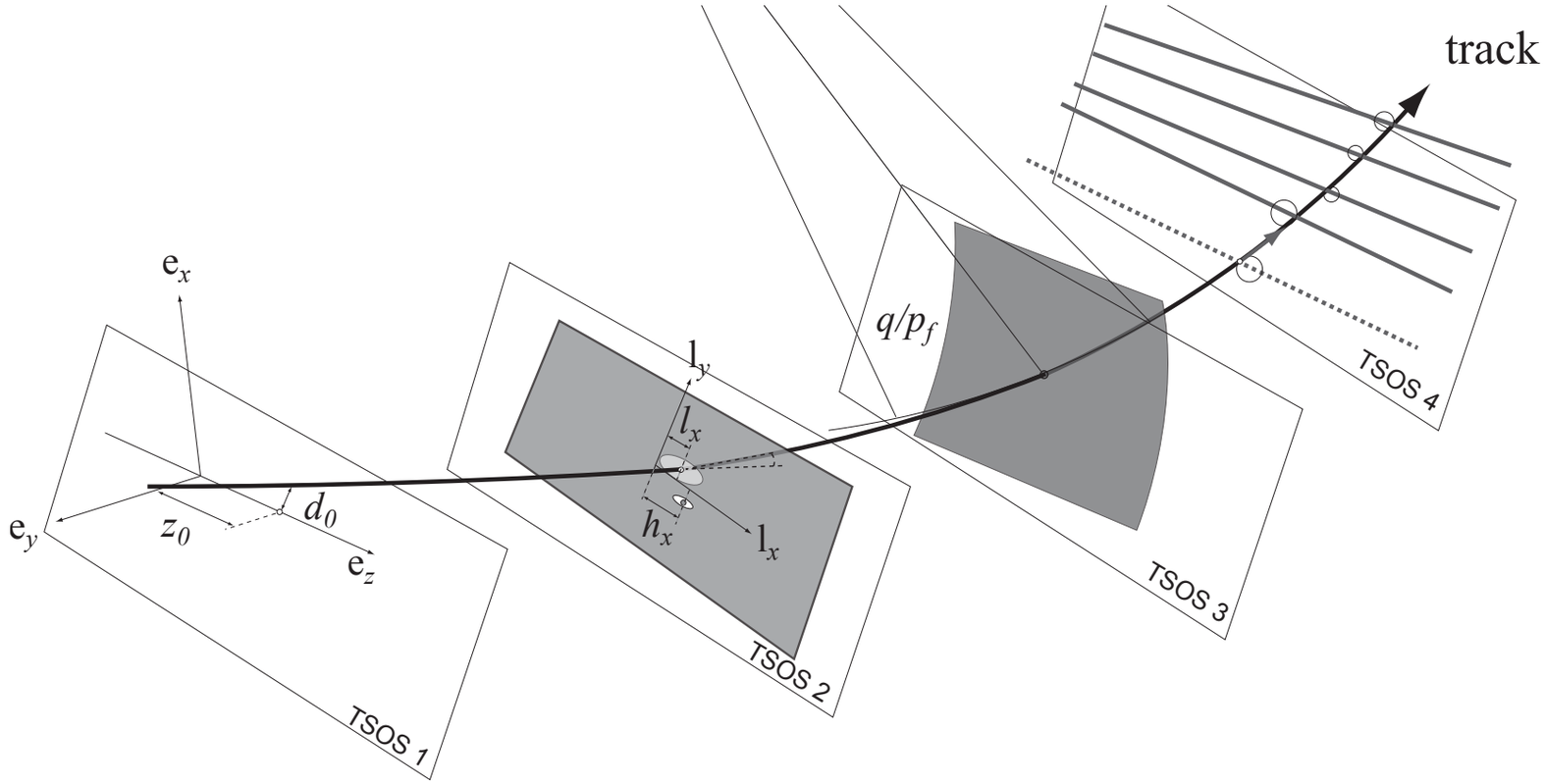
ATLAS $\mathbf{q} = (l_1, l_2, \phi, \theta, q/p)$

Event Data Model - measurements

- Measurements are dynamic-sized
  - possibility to provide each subset of **1–NGlobalPar** dimensional measurements
  - for an ideal/most performant choice:

    measurement mapping functions become projection matrices

```
ParameterSet<loc1,phi> p1(0.5,1.5*M_PI);
cout << p1→get<loc1>() <<endl;   // prints 0.5
cout << p1→get<loc2>() <<endl;   // gives compiler error
cout << p1→get<phi>() <<endl;    // gives -0.5*M_PI
p1→getParameters();              // returns fixed size vector
p1→projector();                  // returns fixed size projection matrix
```

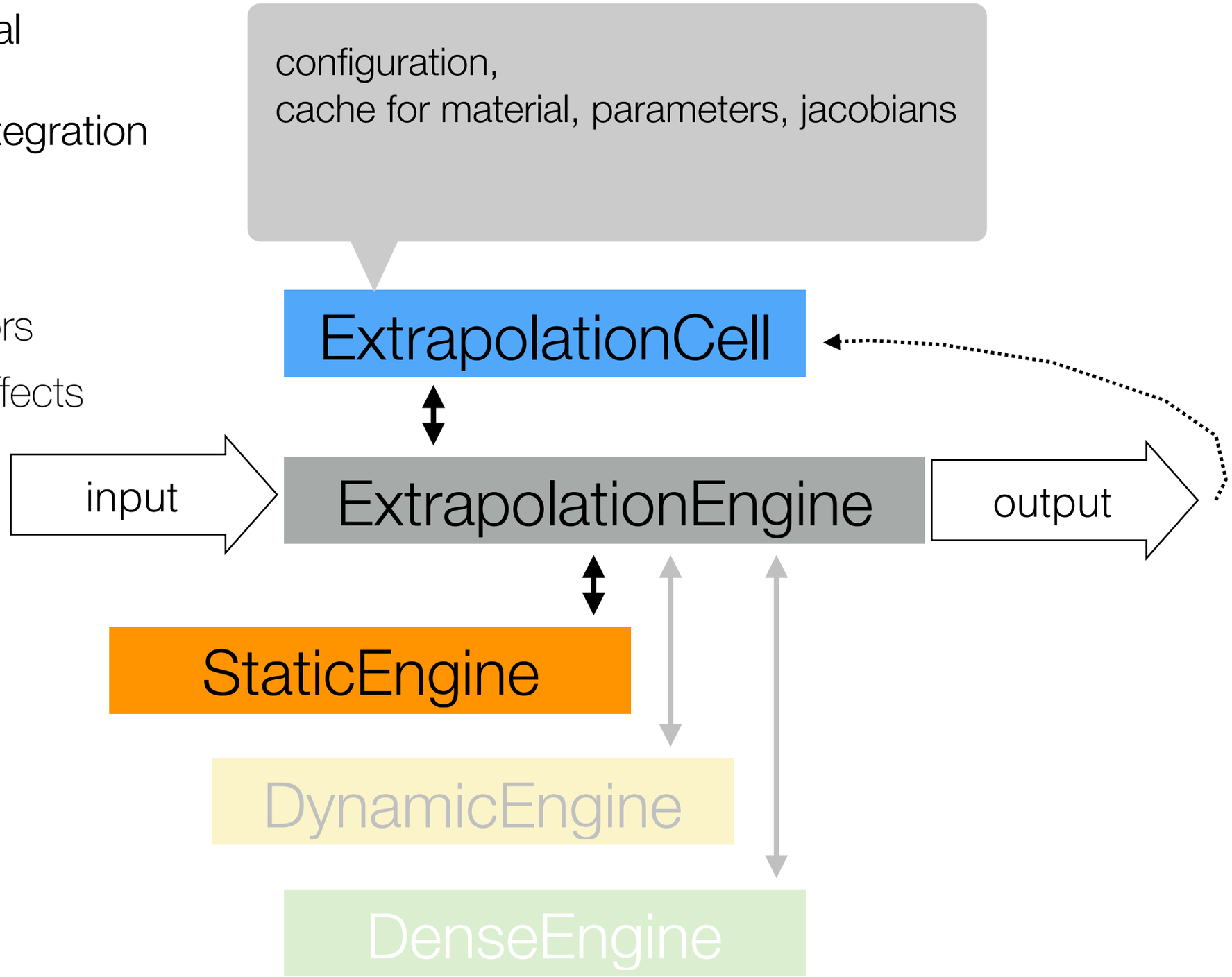


Propagation and Extrapolation

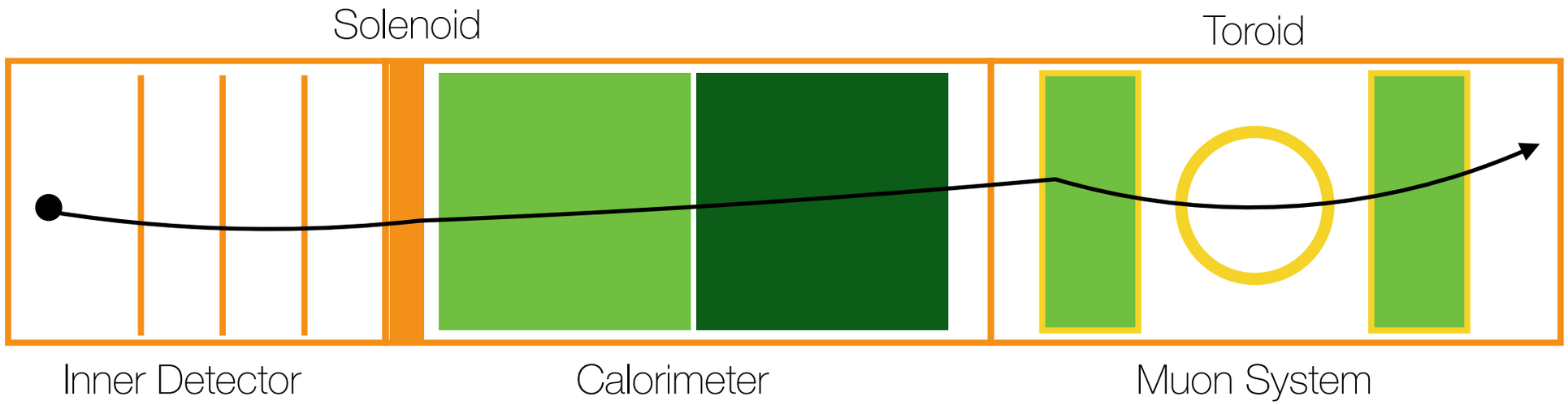
- Extrapolation engine design from ATLAS Tracking SW
  - splits mathematical propagation from material effects integration and navigation
  - allows to plug in:

    different propagators

    different material effects integration



Extrapolation - geometry based



ExtrapolationCell

input

ExtrapolationEngine

output

for fully connective geometry and layer configuration

StaticEngine

for finding “floating objects”

DynamicEngine

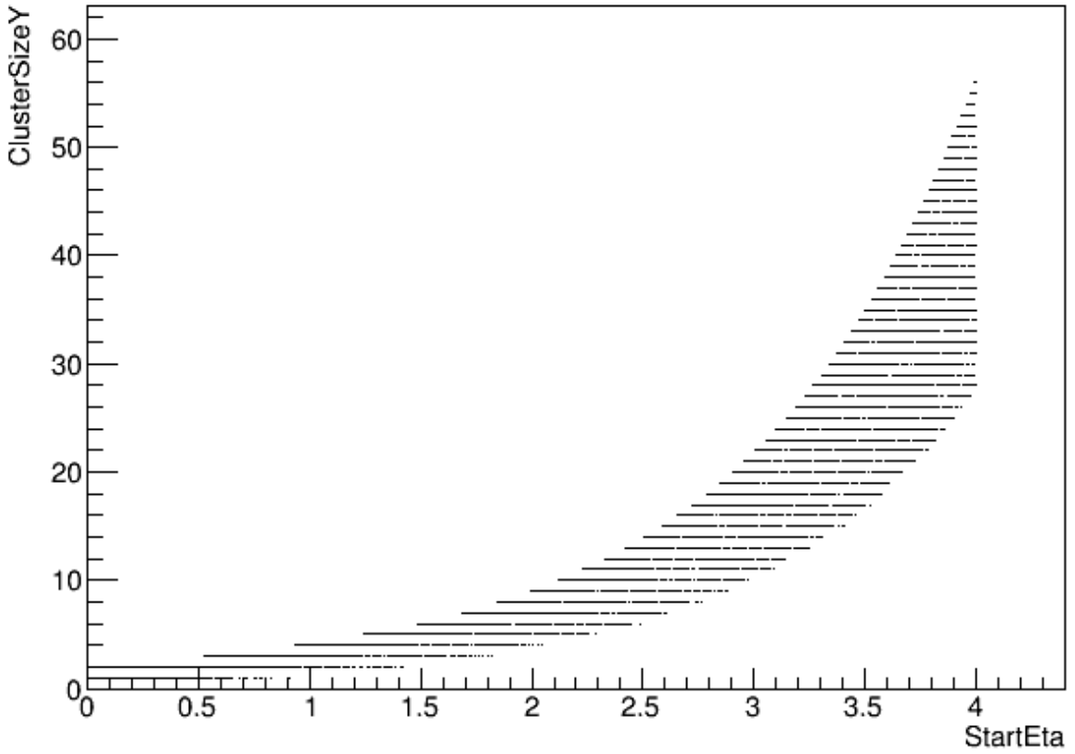
for transport through dense material, using a dedicated STEP propagator

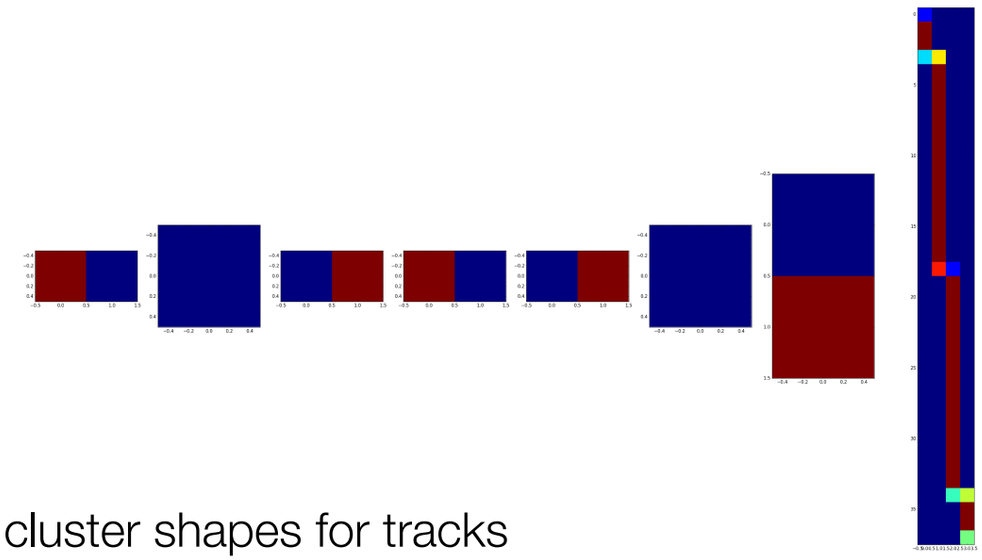
DenseEngine

Fast digitisation

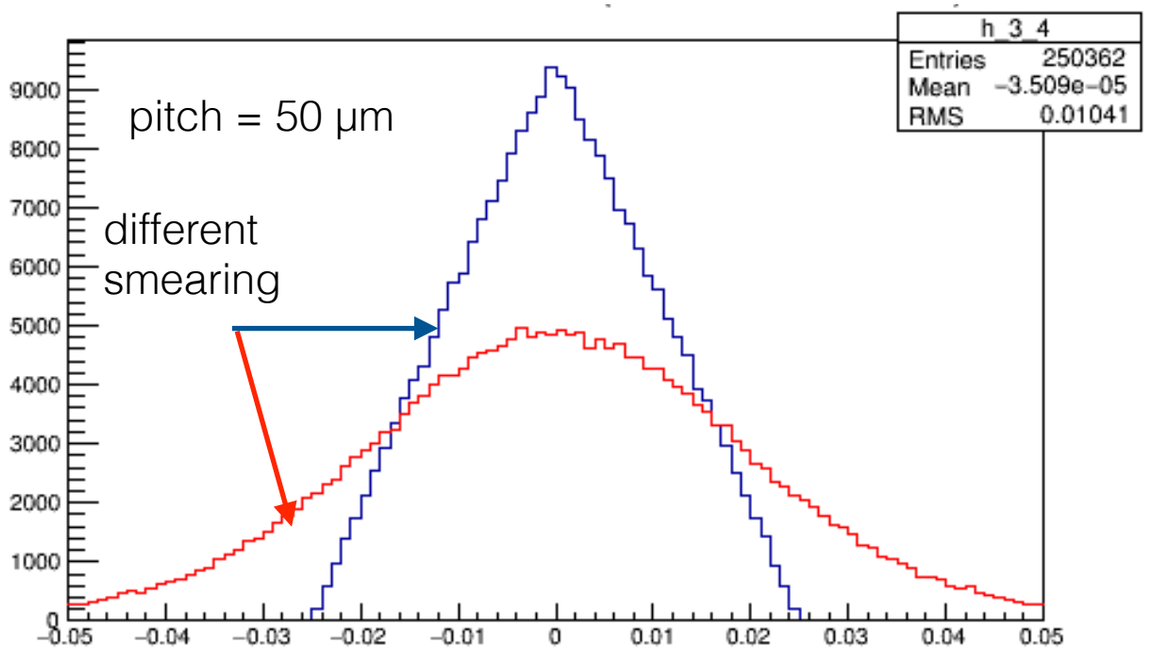
- Geometric digitisation
  - first imported module from ATLAS fast track simulation FATRAS
  - calculates cluster sizes and path lengths in individual pixels

    validated against ATLAS Geant4 simulation
  - takes Lorentz angle into account
  - allows for smearing of charge deposit





cluster shapes for tracks
in Machine Learning dataset (see talk of **S. Amrouche**)



cluster residual in x [mm]

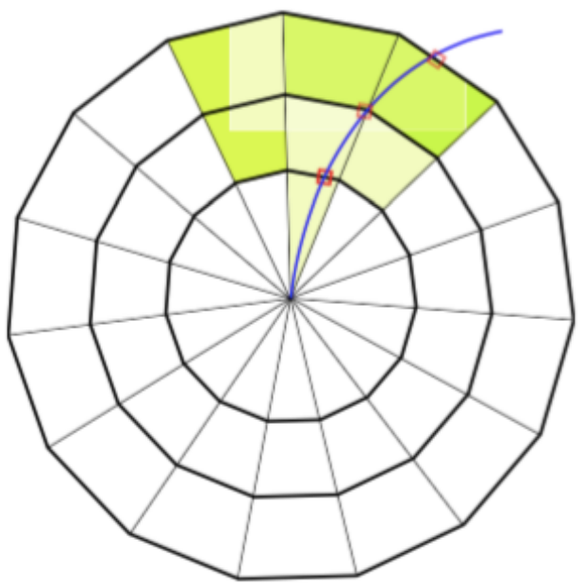
Track finding - mainly plans

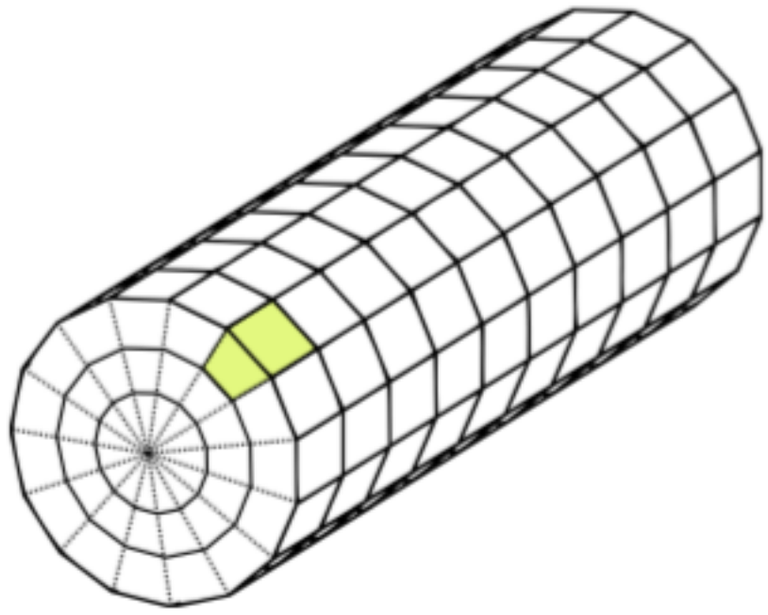
- Track finding modules development has only started
  - plan to import the ATLAS seeding code at first

    currently reviewing the ATLAS track seeding code

    there is some level of caching ongoing (strategy for this developed)

    there is also room for improvement
  - future plan to revive parallel track finding approaches

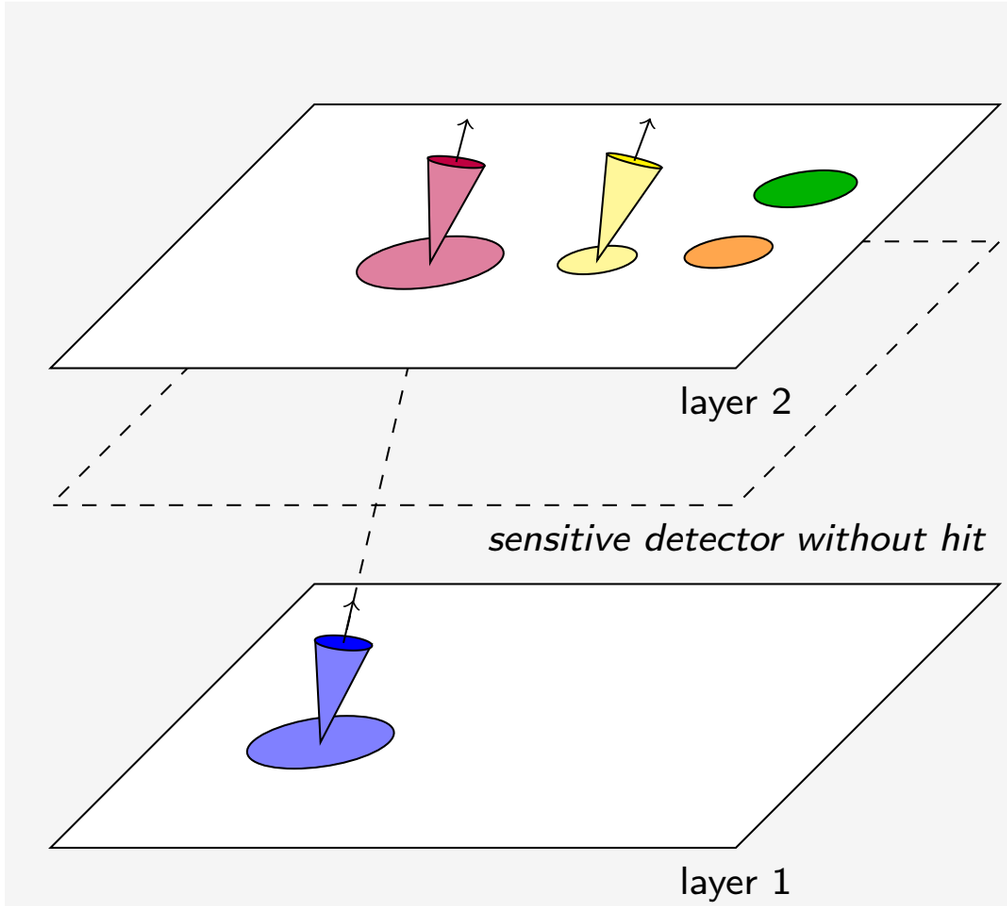


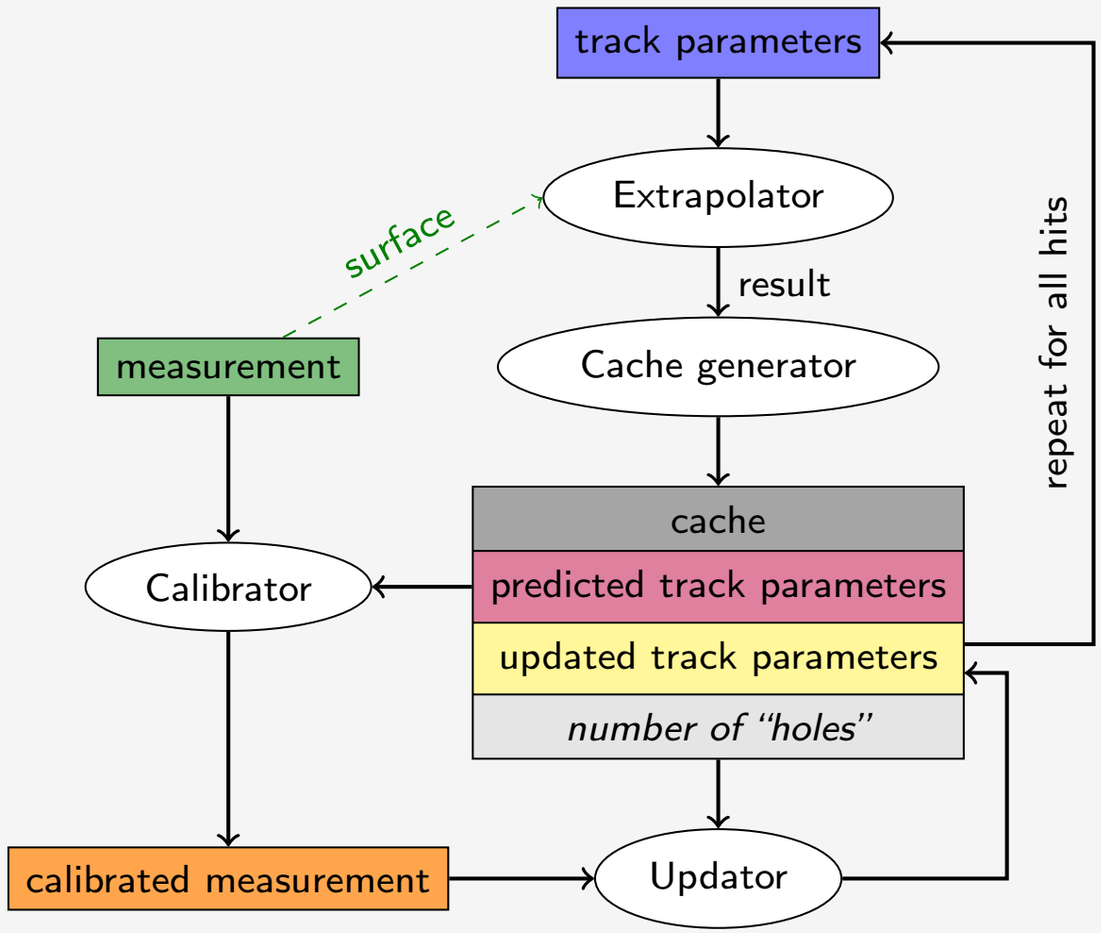


- Track following, candidate classification, etc., <u>room for a lot of ideas !</u>

Track fitting

- First Kalman fitter prototype is implemented
  - gain matrix formalism
  - hole finding on the fly (Extrapolator gives that for free)
  - common backbone with Gaussian Sum Filter, DAF planned





Configuration

- ACTS is framework agnostic and persistency agnostic
  - aim to have a standalone R&D platform
  - do not want to mix persistency issues with data model structure

- Configuration encapsulated in configuration struct objects

```
namespace Acts {
  /// doxygen documentation
  class WorkHorse {
    /// @struct Config for To
    struct Config {
       float coatColour; ///< configure the coat colour
       float maxPath;    ///< set the max path this horse can run
    };
  };
}
```

- Seamless integration in experiment frameworks is a MUST
  - integration to Gaudi-Athena as an example achieved
  - provide a pre-loading of screen logging infrastructure

Concurrency - strategy

- Write non-mutable, const-correct code

- [ ] **Remove every use of "mutable" in ACTS**
  !265 · opened 3 days ago by Hadrien Grasland
  1 1 9
  updated 3 days ago

- Visitor cache objects to allow for stateless engines (that may cache)
  - caller creates a cache which stays local to the thread

```
namespace Acts {
  /// doxygen documentation
  class WorkHorse {
    /// @struct Config for To
    struct Cache {
       float accumlatedPath; ///< configure the coat colour
    };
    /// method to make the horse run
    /// @param hCache - cache tracker for this horse
    /// @param coords - place where the horse should run to
    /// @return a result, horse may drop dead if max path is reached
    const RunResult run(Cache& hCache, const Vector3D& coords) const;

 };
}
```

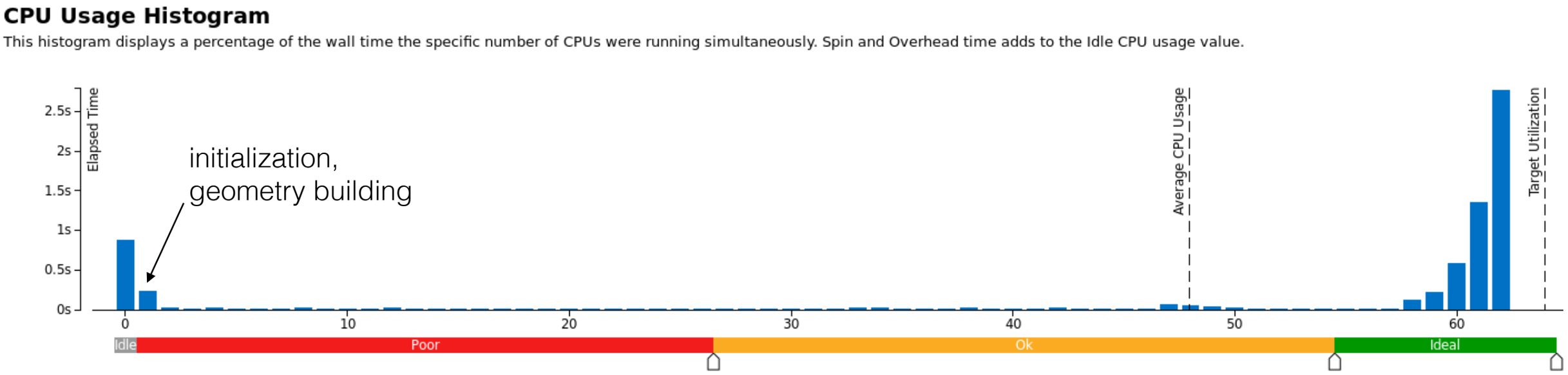
Concurrency - status

- ACTS mini test framework allows for concurrent event processing
  - based on OpenMP, used for development & testing
  - number of threads can be set

- Predictive extrapolation example
  - FATRAS fast simulation without material effects
  - testing the load of up to 64 threads
  - shared geometry and magnetic field

CERN openlab

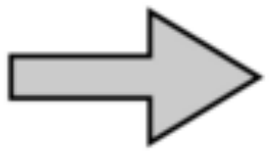
Intel Xeon e5-2698 v3, 2 sockets
32 Cores, 2 threads per core
64 Processors(cpu's)



Vectorised code

- ACTS philosophy is to allow for plug/play mechanism
  - data structures should not stop/prevent vectorisation

```
for(int i=0; i<42; i+=7) {
    double* dR   = &P[i];
    double* dA   = &P[i+3];

    double dA0   = H0[ 2]*dA[1]-H0[ 1]*dA[2];
    double dB0   = H0[ 0]*dA[2]-H0[ 2]*dA[0];
    double dC0   = H0[ 1]*dA[0]-H0[ 0]*dA[1];

    if(i==35) {dA0+=A0; dB0+=B0; dC0+=C0;}

    double dA2   = dA0+dA[0];
    double dB2   = dB0+dA[1];
    double dC2   = dC0+dA[2];

    double dA3   = dA[0]+dB2*H1[2]-dC2*H1[1];
    double dB3   = dA[1]+dC2*H1[0]-dA2*H1[2];
    double dC3   = dA[2]+dA2*H1[1]-dB2*H1[0];

    if(i==35) {dA3+=A3-A00; dB3+=B3-A11; dC3+=C3-A22;}

    double dA4   = dA[0]+dB3*H1[2]-dC3*H1[1];
    double dB4   = dA[1]+dC3*H1[0]-dA3*H1[2];
    double dC4   = dA[2]+dA3*H1[1]-dB3*H1[0];

    if(i==35) {dA4+=A4-A00; dB4+=B4-A11; dC4+=C4-A22;}

    double dA5   = dA4+dA4-dA[0];
    double dB5   = dB4+dB4-dA[1];
    double dC5   = dC4+dC4-dA[2];

    double dA6   = dB5*H2[2]-dC5*H2[1];
    double dB6   = dC5*H2[0]-dA5*H2[2];
    double dC6   = dA5*H2[1]-dB5*H2[0];

    if(i==35) {dA6+=A6; dB6+=B6; dC6+=C6;}

    dR[0]+=(dA2+dA3+dA4)*S3; dA[0]=(dA0+dA3+dA3+dA5+dA6)*.33333333;
    dR[1]+=(dB2+dB3+dB4)*S3; dA[1]=(dB0+dB3+dB3+dB5+dB6)*.33333333;
    dR[2]+=(dC2+dC3+dC4)*S3; dA[2]=(dC0+dC3+dC3+dC5+dC6)*.33333333;
}
```



```
for(int i = 0; i < 42; i+=7){
    __m256d dR = _mm256_loadu_pd(&P[i]);

    __m256d dA = _mm256_loadu_pd(&P[i + 3]);
    __m256d dA_201 = CROSS_SHUFFLE_201(dA);
    __m256d dA_120 = CROSS_SHUFFLE_120(dA);

    __m256d d0 = _mm256_sub_pd(_mm256_mul_pd(H0_201, dA_120), _mm256_mul_pd(H0_120, dA_201));

    if(i==35){
        d0 = _mm256_add_pd(d0, V0_012);
    }

    __m256d d2 = _mm256_add_pd(d0, dA);
    __m256d d2_201 = CROSS_SHUFFLE_201(d2);
    __m256d d2_120 = CROSS_SHUFFLE_120(d2);

    __m256d d3 = _mm256_sub_pd(_mm256_add_pd(dA, _mm256_mul_pd(d2_120, H1_201)), _mm256_mul_pd(d2_2
    __m256d d3_201 = CROSS_SHUFFLE_201(d3);
    __m256d d3_120 = CROSS_SHUFFLE_120(d3);

    if(i==35){
        d3 = _mm256_add_pd(d3, _mm256_sub_pd(V3_012, A_012));
    }

    __m256d d4 = _mm256_sub_pd(_mm256_add_pd(dA, _mm256_mul_pd(d3_120, H1_201)), _mm256_mul_pd(d3_2

    if(i==35){
        d4 = _mm256_add_pd(d4, _mm256_sub_pd(V4_012, A_012));
    }

    __m256d d5 = _mm256_sub_pd(_mm256_add_pd(d4, d4), dA);
    __m256d d5_201 = CROSS_SHUFFLE_201(d5);
    __m256d d5_120 = CROSS_SHUFFLE_120(d5);

    __m256d d6 = _mm256_sub_pd(_mm256_mul_pd(d5_120, H2_201), _mm256_mul_pd(d5_201, H2_120));

    if(i==35){
        d6 = _mm256_add_pd(d6, V6_012);
    }

    _mm256_storeu_pd(&P[i], _mm256_add_pd(dR, _mm256_mul_pd(_mm256_add_pd(d2, _mm256_add_pd(d3, d4)
    _mm256_storeu_pd(&P[i + 3], _mm256_mul_pd(C_012, _mm256_add_pd(d0, _mm256_add_pd(d3, _mm256_add
}
```

- Runge-Kutta integration but up to 2.4x faster using SIMD instructions
- Future CPUs are expected to further extend SIMD capacities

Roberto Agostino Vitillo

Framework integration

- ACTS integration in Gaudi for FCC-hh ongoing
  - ACTS integration for Athena/Gaudi will follow along the way
  - working on a generic GaudiWrapper for Tools/Algorithms
    configuration forwarded from Gaudi `declareProperty` to ACTS config structs

- Persistency mechanism is not part of ACTS
  - currently use ROOT, csv plugins for disk writing
  - could provide data streamers though if needed

- Several build and run-time options available
  - `Identifier` class can be overwritten with the experiment identifier class
  - track parameterisation can be chosen (though derivates, jacobins need to be provided)
  - logging facility can be pre-loaded (in current master, not in 0.03.00)

Conclusions

- ACTS has quite matured during the last year
  - public gitlab project (Core, Test-FW, fast track simulation in preparation)
  - increased functionality, steadily growing

- Toolset for geometry building from different backends
  - supporting different (so far cylindrical) detector geometries
    non-cylindrical detectors can be built, though no automated builders yet available
  - automated material mapping included from Geant4

- Dedicated care on Workflow and code integration
  - continuous integration testing, unit testing
  - documentation and code-style

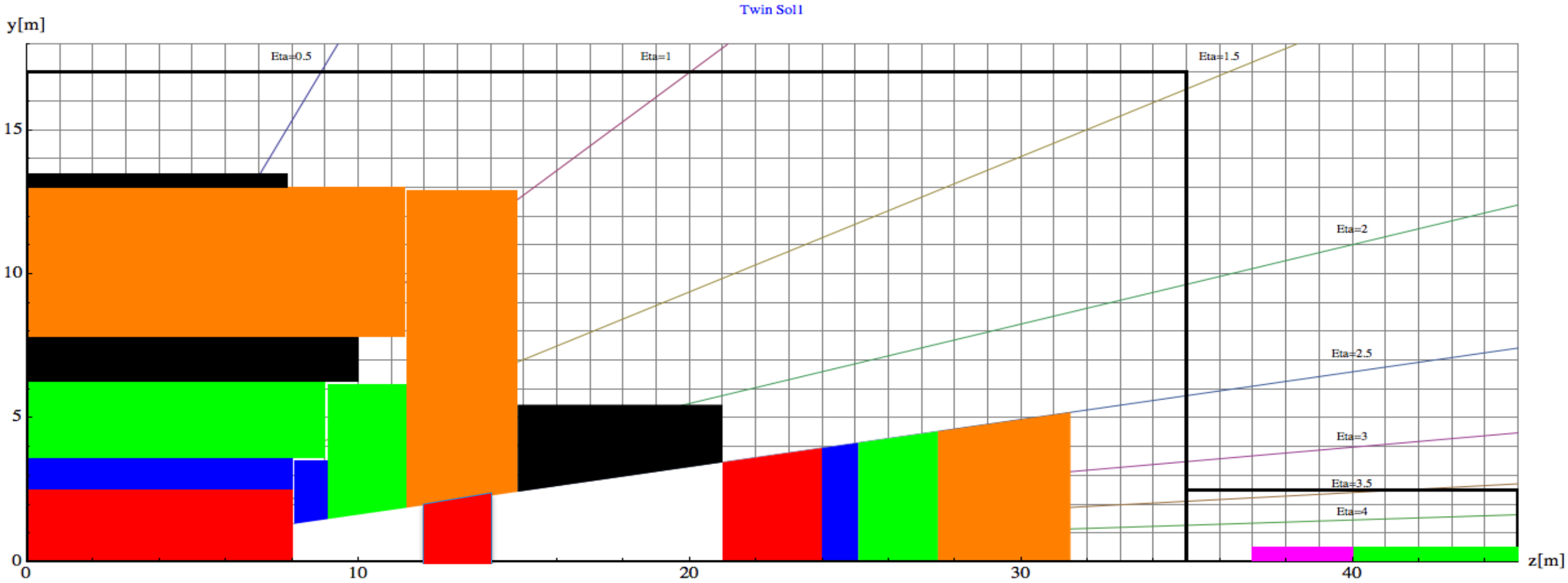
- Keep tuned

Workflow

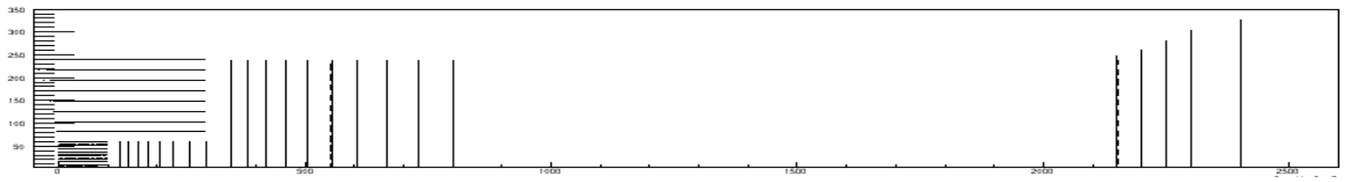
- git-based workflow

Example for TGeoDetectorElement

```
class TGeoDetectorElement : public DetectorElementBase
{
public:
  /** Constructor  */
  TGeoDetectorElement(const Identifier&                                identifier,
                      TGeoNode*                                        tGeoDetElement,
                      std::shared_ptr<const Acts::Transform3D> motherTransform
                      = nullptr);
  /** Identifier */
  virtual Identifier identify() const override;

  /**Return local to global transform associated with this identifier*/
  virtual const Transform3D&
  transform(const Identifier& identifier = Identifier()) const override;

  /**Return surface associated with this identifier, which should come from the  */
  virtual const Surface&
  surface(const Identifier& identifier = Identifier()) const override;
```



DD4hep



ACTS – Fast simulation